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ASTRONOMY.—*On "earth light," or the brightness, exclusive of starlight, of the midnight sky.* W. J. HUMPHREYS. To appear in the Astrophysical Journal.

Investigations begun some years ago by Newcomb,[1] and continued by Yntema,[2] Fabry,[3] Abbot[4] and others, have conclusively shown that there is more light in the midnight sky than can be accounted for by the stars alone. It is not due to nebulae or any other constant source since its brightness varies from night to night and even during the same night; nor can it be caused by anything entirely outside the atmosphere, since it increases in brightness as the horizon is approached.

It has been suggested by Yntema that it may be due, at least in part, to a permanent Aurora, and indeed this is highly probable from the fact that the green "auroral line," $\lambda 5770$, may be seen on almost any dark clear night in any part of the sky.[5]

But there is another possible source of sky light, possibly of the "permanent aurora" itself, that deserves consideration; namely, the bombardment of the outer atmosphere by material of meteoric origin. So far as such a bombardment produces light at all it must be through a considerable depth of the rarer portion of the atmosphere, and therefore it should appear brighter as the zenith distance is increased.

For simplicity of numerical calculations it will be assumed that "earth light" is both constant and uniform—the same over

[1] Astrophysical Journal, 14: 297. 1901.
[2] On the Brightness of the Sky and the Total Amount of Starlight. Gronigen: Gebroeders Hoitsema. 1909.
[3] Astrophysical Journal, 31: 394. 1910.
[4] Annual Report Smithsonian Institution, 1911, p. 64.
[5] Campbell, Astrophysical Journal, 2: 162. 1895.

all parts of the sky, invariable, and continuous. It will also be assumed that whatever the size of meteoric masses, (doubtless the vast majority are but minute grains) their light producing efficiency, or ratio of luminous to total energy, is the same as that of the sun.

With these assumptions it is possible to compute, from known data, the rate at which meteoric material must be picked up to produce the observed amount of "earth light," as follows:

"Earth light" per 10 square degrees = star of first magnitude.

Full moon = star of -11.77 magnitude = 120,000 stars of first magnitude.

Area full moon = 0.2 square degree.

Hence, brightness full moon = 6×10^6 brightness of "earth light."

But the brightness of the full moon is equal to that of a white-mat surface illuminated by a 1200 candle-power light at one meter's distance,[6] or, in symbols, 1200 m.c. (meter candles).

Hence brightness of earth light = 2×10^{-4} meter candles.

Now normal zenith sunshine = 10^5 m.c.,[1] or is 5×10^8 times brighter than "earth light," and consequently delivers 25×10^7 times as much energy per square centimeter as would be radiated from both sides combined of a self-luminous shell equivalent in brightness to "earth light."

Hence, since the solar constant is about 1.92 calories per square centimeter per minute, the total energy used, according to the above assumptions, in the production of "earth light" is

$$4\pi R^2 \times \frac{1.92}{25 \times 10^7} \text{ calories per minute,}$$

in which R is the radius of the earth in centimeters, or

$$27 \times 10^{15} \text{ ergs per second, roughly.}$$

Let this energy be supplied by M grammes of matter moving with the average velocity of meteors, or 42 kilometers per second, then

$$\tfrac{1}{2} MV^2 = 27 \times 10^{15}$$

$$\text{or} \qquad M = 3 \times 10^3 \text{ roughly.}$$

[6] Circular of the Bureau of Standards, 28: 7. 1911.

This is less than three times the amount of meteoric material Young[7] assumes as allowable, and, so far as there is any present means of knowing, may be even less than the actual amount caught up by the earth per second. Indeed it is so small that it would take about two hundred million years for it to increase the radius of the earth a single centimeter!

Numerical calculations, therefore, show that, though not proved, it is within the bounds of reason to assume "earth light" somehow due to bombardment of the outer atmosphere by fine meteoric material; and hence the possible effect of such bombardment should be taken into account in the planning of much needed further observations.

METEOROLOGY.—*Dust layers in the atmosphere and changes in the neutral points of sky polarization.* W. J. HUMPHREYS. To appear in the Bulletin of the Mount Weather Observatory, **4**: pt. 6.

It is well known that sky light is, in general, partially polarized, and that the percentage of polarization varies from one point to another in the sky and also from day to day.

If the light is analysed into vibrations parallel and perpendicular respectively to the horizon, certain neutral arches will appear whose direction at every point makes an angle of 45° with the plane of polarization. If however the analysis of the light is not into these two arbitrary planes, but into the planes of maximum and minimum vibration, and if the direction indicated by the maximum vibration be followed, one is led to a neutral point, the lowest or highest, as the case may be, of the above mentioned arches. The lowest, if it is above either the sun or the antisolar point; the highest, if it is below either of them. In this latter case however, only one of these points, the one below the sun, known as Brewster's neutral point, can be actually observed, the other is always in the shadow of the earth, and, in fact, is purely imaginary.

Along the sun's vertical, but between the sun and its nearly

[7] General Astronomy, p. 475.

equally distant neutral points, Brewster's point below it, and Babinet's above, the polarization plane is parallel to the horizon, as it also is between the antisolar point and its companion, Arago's neutral point. Between Babinet's point and Arago's point however, the plane of polarization along the sun's vertical is perpendicular to the horizon. Hence, when observations are confined to the sun's vertical, as they often are, the neutral points are those points of this vertical at which the two polarizations, vertical and horizontal, are equal.

The vertical polarization is due almost entirely to the primary scattering of solar light by the dust in and the molecules of the atmosphere, while the horizontal polarization appears to be due essentially to secondary scattering. And as both the relative and the absolute intensities of these two quantities of light, as seen by an observer at the surface of the earth, are functions of the amount and distribution of dust in the atmosphere, it follows that the positions of the neutral points must also be functions of the dust in the atmosphere and its distribution; and, as a matter of fact, observations indicate the existence of distinct dust layers with fairly defined upper boundaries.

The first of these, effective in its action on the position of the neutral points when the sun is only about 1° below the horizon, is only that lower and relatively dense layer of dust, seldom more than 1 kilometer thick, that is so frequently seen from mountain tops and from balloons. It is essentially a dry weather condition and is due to dust caught up from the surface of the earth by winds at times when there is but little vertical convection.

The second dust layer, effective when the sun is roughly 3°.5 below the horizon, and therefore extending to an elevation of about 4 kilometers, is due to that great quantity of dust that is distributed thru the atmosphere up to this level at the times of rather strong vertical convection, or at the times when cumulus clouds prevail. It is well known that 4 kilometers is one of the levels of maximum cloud formation—the level of the cumulus cloud. That is, it is the ordinary limit of vertical convection during clear weather. Hence, as a result of this considerable

and frequent mixing of the lower atmosphere, from the surface of the earth up to a level that averages 3 to 4 kilometers, there must in general be considerably more dust up to this same level than there is at greater elevations.

The vertical temperature gradient thru the first 3 kilometers or so, generally is much less than the adiabatic, and hence ordinary convection, cumulus clouds, and, of course, the corresponding dust layer, usually are all restricted to comparatively low levels. Strong cyclonic storms, however, produce convections that overcome the temperature gradient of the lower atmosphere and extend quite to the undersurface of the isothermal region, beyond which level vertical convection obviously can not greatly extend. Dust, therefore, in greater or less extent is distributed, on such occasions, thruout the convective atmosphere, or up to the under surface of the isothermal region, 11 kilometers or thereabouts above sea level.

This then is the third and last possible dust layer of the atmosphere, each layer in turn being of increasing thickness and decreasing density, and all three, but not more, are essential to the physical interpretation of observations on the neutral points of sky polarization.

METEOROLOGY.—*Holes in the air.* W. J. HUMPHREYS. To appear in Popular Science Monthly.

There are, of course, no holes in the ordinary sense of the term in the atmosphere, no vacuous regions, but for all that the picturesque phrase "Holes in the air," is likely to become a permanent acquisition to the language of aeronautics since it is both brief and elegantly expressive of the fact that occasionally there are conditions in the atmosphere which, so far as flying is concerned, are quite like unto holes—conditions that cause sudden drops and disastrous falls.

These may be classified as follows:

1. *Aerial fountains.* More or less vigorous uprushes of air occur over dry heated ground, and especially above barren conical hills, during warm summer afternoons. When the vertical velocity of this heated air is 10 feet per second or more, as it often

is, the inexperienced aeronaut may be seriously disturbed by running suddenly into or out of the rising column. It is probable however that the chief danger is not in the rising column itself but rather at its top where, as we see by the motions of the heads of cumulus clouds, there is great turbulence and a confusion of currents.

2. *Aerial cataracts.* Downrushes of air, like the uprushes with which they are associated, must also be most frequent during warm weather when the ground is strongly heated. But though annoying to the beginner they should not be dangerous to the experienced aviator, because, however strong their descent at considerable elevations, they necessarily become horizontal before the surface is reached.

3. *Aerial cascades.* The swift downward sweep of the wind on the lee side of steep mountains tends to carry the aviator with it to lower levels, but this in not a source of danger unless by flying low he gets caught in an eddy.

4. *Wind layers.* As fair weather is giving way to foul sharply defined layers of air often slide over each other in different directions and with different velocities, and by so doing produce one of the most serious dangers the aeronaut has to confront. Suppose, for illustration, that in making a straight away glide with the engine at rest the aeronaut should suddenly enter a wind layer moving in the same direction and with the same velocity. Under these extreme but possible conditions all dynamical support and all power of adjustment are instantly lost and a drop, either to the earth or until a considerable velocity with reference to the air is again obtained, is inevitable. Such an extreme case of course is unusual, but less extreme cases are frequent, and since the support is proportional to the square of the velocity of the machine with reference to the air even a comparatively small decrease in this velocity may cause a considerable drop, which, if begun near the surface of the earth, may well be dangerous.

5. *Wind billows.* Wind layers, as they glide over each other, are thrown into billows quite like unto water billows under the influence of strong winds; and since they mark the boundary of currents of different velocity or direction or both, it obviously

is not safe, as just explained, for an aeroplane to take the billow level and thus pass back and forth from the one to the other wind layer.

6. *Wind eddies.* Wherever the wind is forced by obstructions markedly to change its direction, and wherever it flows over steep hills and mountains eddies are certain to exist. These generally are most marked during strong winds and on the lee sides of steep hills and bluffs. The upper portion of the eddy moves in the same direction as the prevailing wind to which it is due and the under portion in the opposite direction. Hence in passing thru such an eddy an aeronaut may, as explained under "wind layers," get into serious trouble. He may also get caught on the forward side of the eddy and be rapidly carried down. Therefore during strong winds the lee sides of hills and bluffs should be avoided.

7. *Aerial torrents.* Air drainage down steep and barren valleys occasionally amounts to a veritable aerial torrent near the surface of the earth while the atmosphere directly above is relatively at rest. Hence it necessarily must be dangerous to land an aeroplane under such circumstances, and especially so, as above explained, if it is headed with the torrent.

8. *Aerial breakers.* At the onset of thunder storms the wind often is of the breaker nature, violent and irregular, and therefore so dangerous to the aeronaut that it would be fool hardy to attempt a flight under such conditions.

CLASSIFICATION

All the above atmospheric conditions may conveniently be divided into two groups with respect to the method by which they force an aeroplane to drop as if in a hole of some kind:

a. The vertical group. All those atmospheric conditions, fountains, cataracts, cascades, breakers, and eddies that, in spite of full speed ahead with reference to the *air*, make it impossible for an aeronaut to maintain his level depend for their effect upon a vertical component in the motion of the atmosphere.

b. The horizontal group. Those conditions of the atmosphere,

wind layers, billows, torrents and the like, that, in spite of full speed ahead with reference to the *ground*, abruptly deprive an aeroplane of a portion of its support, owe their effect to a running of the wind more or less with the machine.

Both groups are sources of danger to the aeronaut and therefore he should become well acquainted with the meteorological conditions under which and the places at which they are most likely to occur. But this is a story whose details are beyond the scope of the present article.

METEOROLOGY.—*Hurricanes of the West Indies and other tropical cyclones.* OLIVER L. FASSIG. Communicated by W. J. Humphreys. To appear as a special Bulletin of the U. S. Weather Bureau.

An analysis of 135 storms of hurricane force that occurred in the West Indies, as recorded by the U. S. Weather Bureau, from 1876 to 1910, shows that there is a well marked path of greatest hurricane frequency which, beginning near the Windward Islands, runs nearly due west across the northern half of the Caribbean Sea to Jamaica, gradually turns northwest, passes thru the Yucatan Channel, recurves in the eastern portion of the Gulf of Mexico, and finally, after crossing the Florida Peninsula, passes out over the North Atlantic with a northeast trend.

A secondary hurricane path, not so well defined, extends from the northern group of the Windward Islands in a west-northwest direction across the Bahamas and, recurving east of Florida, passes out also northeasterly onto the Atlantic. Tho the Greater Antilles lie between these paths two of them, Porto Rico and Haiti, are comparatively free from the devastating winds near the hurricane centers. The western half of Cuba, however, is crossed in the recurve of a large percentage of the Caribbean storms that belong to the main path.

From the above descriptions it will be observed that the two storm paths closely coincide with the two branches of the great equatorial current of the North Altantic.

In both cases the normal path for the entire season resembles a parabola, though the exact path pursued by an individual

storm depends to a great extent upon the point of its origin, which indeed may be at any portion of the track. (Of 134 individual storms examined 84 originated in the first branch of the normal track, 23 in the recurve and 27 in the second branch.) But wherever the storm may originate, for the balance of its existence it will follow approximately the normal path for the month in which it occurs. Thus those that originate far to the east, as they generally do in August and September, are most likely to move west-northwest for a considerable distance before recurving, while those that originate in the western waters of the Caribbean Sea, as do most of the storms early in the season and also those of October, move northwest or north along the recurve of the normal track.

The following tables give some of the more important facts in regard to hurricanes.

HURRICANES OF 1876–1900

	MONTH OF OCCURRENCE						
	May	June	July	August	September	October	November
Number of storms	1	8	5	33	43	42	2
Percentage of total	1	6	4	25	32	31	1

MEAN VELOCITY OF 136 STORMS

	LOCATION		
	First branch	Recurve	Second branch
Miles per day	260	260	390

DURATION OF HURRICANES IN FIRST BRANCH AND IN RECURVE

NUMBER OF EXAMPLES	DURATION IN DAYS								
	1	2	3	4	5	6	7	8	9
First branch	15	21	16	7	7	13	4	1	1
Recurve	26	46	15	5	3	2			

AREAS WITHIN WHICH TROPICAL CYCLONES ORIGINATE

NAME	LATITUDE	LONGITUDE	MEAN ANNUAL FREQUENCY
Hurricanes (West Indies).....	12°–28° N	55°–95 W	4
Cyclones (Bay of Bengal).....	8°–22° N	80°–100° E	9
Typhoons (North Pacific).....	5°–20° N	115°–150° E	20

Conditions favoring the formation of the West Indian and other cyclonic systems in the tropics are produced by changes in the positions and intensities of the so called permanent areas of high and low atmospheric pressure incident to seasonal changes and to variations in the intensity of isolation. Hence there are three and only three regions, as listed above, all more or less similar, in which destructive tropical storms originate. Once formed these systems are carried along in the general drift of the atmosphere—from east to west below about latitude 30°N., and from west to east in higher latitudes.

PHYSICS.—*New methods for displacement measurements and temperature uniformity applied to the determination of linear expansivity.* ARTHUR W. GRAY. Bureau of Standards. Communicated by L. A. Fischer.

This communication describes certain improvements in two of the fundamental operations involved in the determination of linear expansivity, viz., (1) The measurement of displacements that occur within places difficult of access, and (2) The production of uniform temperature thruout an extended region. The paper concludes with pointing out how the methods set forth might find a special application in the problem of gas thermometry. Some features were outlined at the Washington meeting of the American Physical Society in December, 1911.[1]

The measurement of inaccessible displacements. Essentially the method consists in determining the displacement of an inaccessible point by observing a stretched wire so arranged that its motion follows that of the point in a known way. In order to eliminate from the measurements any elongation of the wire,

[1] A. W. Gray, Phys. Rev. 34: 139. 1912.

whether from thermal expansion or other sources, the direction in which it is stretched should be as nearly as possible perpendicular to the displacement. This procedure of arranging the link connecting the accessible with the inaccessible region at right-angles to the displacement is, perhaps, the most important feature of the method; and it is applicable to a greater or less extent in mechanical schemes for transferring motions thru the intervention of rods as well as of wires.

Two simple arrangements in which the principle has been successfully applied for determining the linear expansion of bars are represented diagramatically by figs. 1 and 2. In each the expanding bar

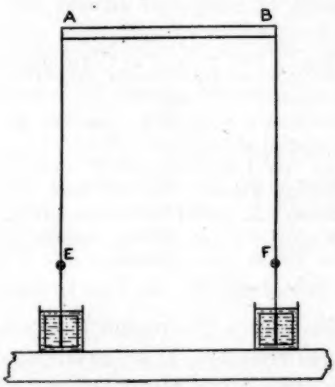

Fig. 1. Elongations by method of suspended wires.

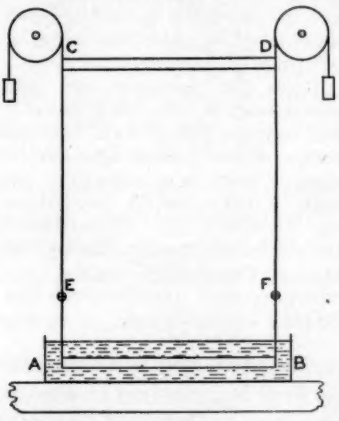

Fig. 2. Elongations by method of stretched wires.

is indicated by AB. In the former, wires are freely suspended over the ends of the bar and stretched vertically by the weight of vanes immersed in oil, the viscosity of which is adjusted to damp any swinging of the wires so that their motions will be almost, but not quite, aperiodic. In the latter, suitable for cases in which the bar is immersed in a liquid, wires are stretched upward to another bar CD rigidly connected with the central portion of AB. In both arrangements the motions of the wires are observed through micrometer microscopes focused at convenient points E and F. A piece of thin white paper, illuminated from behind by a small incandescent electric light form a bright background most agreeable to the eye, on which a wire stands out as a dark bar with smooth, straight edges. Disturbances from changes in level of

AB are avoided by grinding its ends to form portions of a horizontal cylinder, the axis of which passes thru the center of the bar. The wires should be protected from air drafts.

In the arrangement of fig. 1 the change in the distance separating the wires is the same as the elongation of AB. When adjustments are properly made, the damping is so effective that the wires appear perfectly still without the need of any such stable support as a pier; yet if disturbed, even by such vigorous treatment as removing and replacing the oil bottles, they promptly return to their original positions. Repeated trials have shown that a precision of better than a micron is easily obtainable in measuring the distance between two wires thus suspended.

In the arrangement of fig. 2 deduction of the length of AB from the measurements is a simple matter. The influence of possible changes in CD can be rendered negligible by suitably controlling its temperature and by placing it far enough away from AB and EF; but if this is not feasible, the proper correction can usually be computed without difficulty.

Since the passages thru which the wires enter the inaccessible region may be very long and of cross-section barely sufficient to permit free motion, the effect of the openings upon conditions within (such as temperature distribution) can be reduced to a minimum. If it is desired to work in a vacuum, or in some special atmosphere, the passages may be extended on the outside by an envelope completely incasing the wires and the external bar or damping vanes. The motions can be observed through plate-glass windows. A further decided advantage of the method consists in eliminating certain optical difficulties which present themselves when direct vision thru openings into the interior is attempted.

The production of temperature uniformity. If a region in which no heat is generated or absorbed be surrounded by an isothermal envelope maintained constantly at the same temperature, all points within will ultimately come to this temperature. The approach to thermal equilibrium will be hastened by anything which increases the influence of radiation, conduction, or convection within the region. The main difficulty of the problem, then reduces to that of securing such an isothermal envelope.

If the region in question has, by any suitable means, been heated uniformly to the desired temperature T, then any procedure which will eliminate heat loss or gain at every point of the surface will maintain T constant and uniform. The rate dQ/dt at which heat will be conducted away from any portion of the bounding surface in consequence of a normal temperature

gradient $-dT/dN$ and a thermal conductivity k in the surrounding substance, will be directly proportional to both dT/dN and k. Encasing the region in a poor conductor of heat will reduce the latter, and making the layer thick will reduce the former; but this procedure will never eliminate completely either of these factors. However, dT/dN and, consequently, dQ/dt can be made to vanish by supplying heat around the surface in such a way as to compensate exactly for the loss at every place. But the accurate regulation of such a supply presents difficulties which augment rapidly as T departs from the surrounding temperature, because the increased heat flow involved is subject to greater irregularities of surface distribution and to greater fluctuations with time. Conductivity parallel to the boundary, or the much more efficient action of a circulating fluid, will promote a uniform distribution of both the losses and the supply. The usual practice of abundant thermal insulation outside the source of heat will reduce variations in the former but not in the latter. But the effect that variations in either will produce upon the temperature of the region to be controlled can be materially lessened by the introduction of an insulating layer between the region and the source; since the mere separation of the two will reduce the already small dT/dN and also its rate of change $\frac{d}{dt}\left(\frac{dT}{dN}\right)$ at the surface of the former, while the reduction in k will still further lessen dQ/dt and d^2Q/dt^2. Whatever variations continue to exist near the region can be still further reduced by applying a small, properly regulated supply of heat around the surface, but best separated from it by an insulating layer for the reasons just given.

Neglect of certain of the conditions discussed above is quite justifiable where simplicity of construction and operation is more essential than refinement of temperature control. However, proper design of the temperature bath and its accessories can go a long way towards realizing the ideal conditions without introducing troublesome complications.

Attention is first directed to a simple device in which the principles just enunciated have been successfully employed to reduce the long-

itudinal temperature gradient in a tubular air bath of considerable length. It is a plug formed of two thick blocks of a good heat conductor united by a thin shell and separated by a considerable layer of a poor conductor. Fig. 3 represents one in each end of a tube the circumference of which is heated by a fluid circulating spirally around it and returning to the inlet end by linear flow through an outer concentric passage. In such a return-flow tube, whose ends were plugged for 10 cm. essentially as indicated, though not quite so well, an air column 4 cm in diameter and more than a meter long has been repeatedly heated by circulating oil to over 100°C. so uniformly thruout its entire length that right against the plugs the temperature was only a few hundredths of a degree lower than in the center, while several centimeters farther inward the drop was only a few thousandths. Yet with

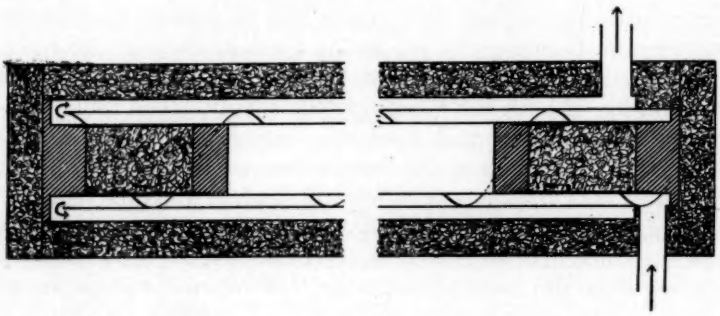

Fig. 3. Oil-heated return-flow tube showing double plugs to reduce temperature gradient.

the ends closed by equally long plugs of such heat insulators as cotton-wool and cork there was a marked lowering of the temperature in the immediate vicinity within, even when the interior was only slightly warmer than the room; and in many of the experiments made this drop was apparent for a long distance within the tube. If the inside tube (of brass 1 mm. thick) were extended 4 cm. beyond the heating jacket, relatively enormous end effects were produced in the air column, especially if the projections were not well protected by lagging. But unhindered radiation and conduction through the sides of the tube to the surrounding air was found to disturb the distribution of temperature within only slightly. In nearly all cases where the tube was not surrounded by an insulating jacket, there was evidence of a small progressive drop in temperature in the direction away from the inlet and exit end. Doubtless this could have been made imperceptible by substituting a poorly conducting tube for the thin brass one separating the oppositely directed currents of heating fluid.

One important object of the experimental study that developed the simple plug just described was to secure data for improving the design of electric furnaces, especially in the direction of bettering the distribution of temperature. The return-flow, oil-heated tube was used in order to secure uniform lateral heating, and thus to avoid confusing the observations by the effect of such irregularities as would be almost sure to exist in an electrically heated helix, no matter how carefully wound.

Previous experimenters have tried to secure uniformity of temperature in an electrically heated air column by using the central portion of a sufficiently long tube and by crowding the windings near the ends or other places where heat was lost most rapidly. In this way Daniel Berthelot[2] secured uniformity within 2° over the central 22 cm. of a tube 85 cm. long heated to 917.° Jaquerod and Perrot[3] in a well-insulated furnace without crowded windings heated a gas thermometer bulb 8 cm. long with variations of less than 2° at 1066°. Waidner and Burgess[4] constructed a black-body in which compensation for heat losses thru the ends was secured in great measure by the use of a second independent heating coil surrounding the first and projecting 8 cm. beyond each end. The winding of the secondary coil was very close about the ends and very open about the center. At 1244°.9 this arrangement gave such remarkably uniform temperature that there was no variation of more than one or two tenths of a degree over a length of 12 cm. However, the method of varying the distribution of heat supply to compensate for lack of uniformity in the distribution of heat losses suffers from two serious defects: (1) It is a method of cut and try. (2) The proper arrangement to secure uniformity at one particular temperature does not give uniformity at any other temperature, necessitating a repetition of the cut and try process for every temperature desired. This is strikingly illustrated by one of the compensated black-bodies of Waidner and Burgess. While the temperature

[2] D. Berthelot, Ann. Phys. et Chim. 26: 119. 1902.

[3] A. Jaquerod and F. L. Perrot, Archives des Sciences Phys. et Nat. 20: 45 and 57. 1905.

[4] C. W. Waidner and G. K. Burgess, Bull. Bur. Standards 3: 165. 1907.

uniformity was practically perfect for 12 cm. in front of the radiating diaphragm at 1244°.9, drops of 8°, 10°, and 11° took place within the second 4 cm. of this same region when the diaphragm was at 621°, 1041°, and 1308°, respectively. Day and Sosman[5] made five separate attempts to wind a tubular furnace with two small side openings so that it would produce a uniform temperature along a platinum-iridium bar 25 cm. long, the linear expansivity of which they were determining. The deviations that they report within the central 24 cm. of their two most successful furnaces amount to 5° at 300°, increasing steadily to about 20° at 700°, and reaching about 50° at 1000°. While the thick-walled iron tube used in these latter trials produced markedly better results than the porcelain tube used in the earlier ones; still it is quite clear that even the conductivity of the iron was very far from adequate to secure uniformity, expecially at temperatures much removed from the one at which a particular distribution of the heating coils gave the best results.

The double plug with small temperature gradient across an insulating layer, which was described above, indicated a way of reducing such difficulties as have just been enumerated. Accordingly, an electrically heated furnace was constructed for determining the expansivity of bars, the elongations being measured by the suspended-wire method outlined in the first section of this paper. Fig. 4 represents the essential features.

Since this furnace was designed primarily for convenience of manipulation and for securing merely moderate uniformity of temperature, only a partial use was made of the principles enunciated on page 251. The furnace tube, of iron fairly uniformly wound for its entire length with constantan ribbon, had its central portion completely filled with an iron block pierced by two longitudinal cavities, of square cross-section, symmetrically situated above and below the geometrical axis of the tube. The lower cavity was almost completely filled by the bar to be measured, while the upper one contained a similar dummy bar, the temperature of which was determined by a thermo-element placed within a hole following the axis of the bar. While the conductivity of the large metal masses probably contributed considerably toward the production of temperature uniformity within this furnace, and while

[5] Described in a paper by A. L. Day and J. K. Clement, Am. Jour. Science **26**: 425. 1908.

the smallness of the passages required for the suspended wires certainly prevented much disturbance, a very important feature of the whole construction was undoubtedly the type of plug used for closing the ends. This was essentially the same as the simple one described above, with the addition of an independent electrical heating coil wound in a groove within the outside conducting block. This coil made it easy to maintain the end at a temperature almost the same as that of the interior, thus reducing the longitudinal temperature gradient and thereby the outward conduction of heat. Suitably arranged differential thermoelements in the plugs, together with a convenient grouping of rheostats, make the temperature control an easy matter.

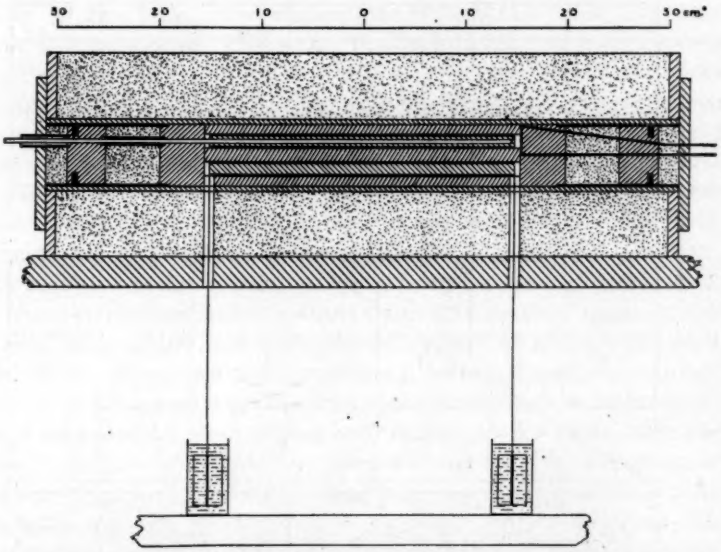

Fig. 4. Electrically-heated furnace for expansion measurements by method of suspended wires, showing double plugs with outside ends independently heated.

The furnace was built to accommodate bars 30 cm. long. Examination of the temperature distribution throughout this length for various temperatures up to 684°C. showed that, if the outside end of the plugs was within 10° of the interior, no variation exceeding a few tenths of a degree occurred in the right-hand 15 cm. except at the highest temperature to which the furnace was forced, when the extreme deviation was found to be 4°. Since the constantan ribbon burned out in the vicinity of the hottest place the next day, considerably before this temperature was again reached, it seems likely that this deviation was due to exces-

sive local heating. The left-hand half of the bar was not, however, so uniformly heated as the right and was consistently warmer, the maximum rise of 2° occuring in the second 5 cm. from the left end. The most plausible explanation is irregularity in either the heating coil or the insulation at this place. It is to be noted that the thermal conductivity of such a large mass of iron as was used proved still insufficient to produce a uniform distribution; and further that the distribution observed at any one temperature did not differ essentially from that observed at any other. Even making the outer ends of the plugs considerably colder than the interior affected the temperature within but little.

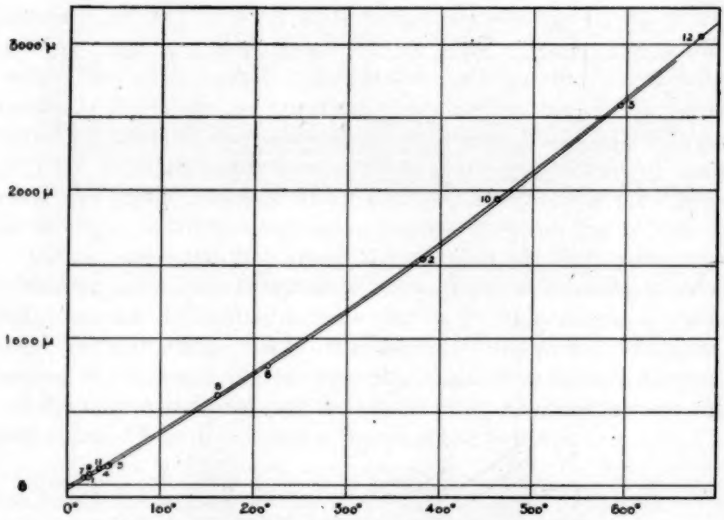

Fig. 5. Expansion of annealed cold-drawn Bessemer steel

Changes in this furnace are now in progress for securing a fuller application of the principles discussed at the outset of this section. Two concentric heaters separated by an insulating layer are provided, and a recently devised scheme of longitudinal winding is introduced to facilitate, among other things, uniform distribution of the heat supply.

It is apparent that the end-heated plug, conducting transversely while insulating longitudinally, affords a ready means of preventing heat loss for any temperature of operation, and, consequently, the entire interior, regardless of its length, will be

uniformly heated if lateral loss and supply are uniformly distributed by some such construction as that just outlined in the preceeding paragraph. And in cases where it may not be practicable to heat the ends as hot as the interior, much is still to be gained by bringing them as near to the proper temperature as circumstances permit.

The expansion of cold-drawn Bessemer steel. Some results obtained on the first trial of the methods outlined in this paper are exhibited by Fig. 5, which shows the expansion of a steel bar 30 cm. long. The elongations were measured by sighting on platinum wires 1/30 mm. in diameter suspended over the ends as indicated in Figs. 1 and 4. Changes in the distances separating the axes of the observing microscopes were determined by reference to wires similarly suspended from another bar kept so nearly at a constant temperature that any changes in it could readily be calculated. The unannealed cold-drawn steel was first subjected to several alternations in temperature, extending from that of the room up to between 150° and 380°. In conformity with the experience of other observers, the bar was always found noticeably shorter upon cooling than when at the same temperature before the preceding heating; and it was found to return slowly towards its original length if left undisturbed at room temperature. The bar was then heated to about 800° and annealed by slow cooling over night. A few days later the measurements represented by the lower curve in Fig. 5 were made in the order indicated by the numbers, the curve passing almost exactly through all the points obtained. After allowing the bar to rest undisturbed for about a month, a new series of similar measurements was made with the upper curve as the result. The lengthening accompanying the period of rest seems to have extended throughout the whole temperature range—nearly 700°C.

A suggested application to gas thermometry. Thermal expansion of the material forming the thermometer bulb necessitates corrections for changes in volume, which become of increasing importance as the temperature range is extended. The difficulties involved in determining this expansion have been recognized by investigators in the field of precision of gas thermometry.

Jaquerod and Perrot[6] sought to avoid them by the use of fused silica, whose expansivity is small. Day, Clement, and Sosman[7] conducted elaborate secondary investigations to determine the linear expansivity of rods, the composition of which was made as nearly as possible the same as that of the bulb, though the physical treatment of the two must of necessity have been decidedly different. Apparently, however, in no case have changes in the dimensions of the bulb itself been measured simultaneously with the measurements of pressure necessary to determine the temperature.

The possibility is here suggested of accomplishing this by the method described in the first section of this paper. The wires for transferring the displacements could be applied to the ends of a thermometer bulb, the capillary of which is placed a little to one side of the axis for the purpose of leaving the adjacent end unobstructed. These same measurements yield the expansivity of the material of the bulb, using the bulb itself as an integrating thermometer. The openings necessary for the wires can be arranged so as not to disturb the temperature distribution within, and can be used for admitting a gas to equalize the pressure on both sides of the bulb walls.

It is obvious that the method, which determines total linear change, whether arising from thermal expansion or other influences, could be used for following alterations of the bulb in other directions.

It is also suggested that the methods of temperature control discussed above might possibly be advantageously employed in this connection.

[6] A. Jaquerod and F. L. Perrot, Archives des Sciences Phys. et Nat. 20: 35. 1905.

[7] A. L. Day and J. K. Clement, Am. Jour. Science 26: 405. 1908. A. L. Day and R. B. Sosman, Am. Jour. Science 29: 93. 1910.